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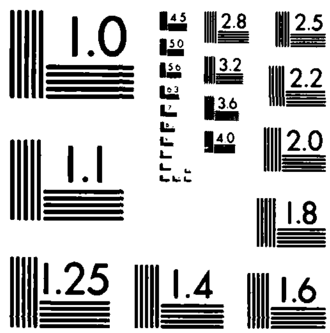

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AD-A155 369

METHODOLOGY UNDERLYING COSTCASTER, A COST-PREDICTION AND TRADE-OFF MODEL FOR AIR FORCE GROUND C-E EQUIPMENT

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— STATISTICS —

— OPERATIONS RESEARCH —

— MATHEMATICS —

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Applied Research in Statistics - Mathematics - Operations Research

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COSTCASTER is a cost-prediction and trade-off model currently under development by Desmatics, Inc. for the Air Force Office of VAMOSC. The model is designed for use as a decision aid in determining whether to modify, replace, or retain items of Air Force ground communications-electronics (C-E) equipment at the Type-Model-Series level. This report discusses the mathematical and statistical methodology underlying the COSTCASTER model.

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EXECUTIVE SUMMARY

COSTCASTER is a cost-prediction and trade-off model currently under development by Desmatics, Inc. for the Air Force. The model is designed for use as a decision aid in determining whether to modify, replace, or retain Air Force ground communications-electronics (C-E) equipment. This report discusses the mathematical and statistical methodology underlying this model.

As an initial processing step, the COSTCASTER preprocessor builds an historical data base for C-E equipment, using annual cost and maintenance data supplied by Air Force data systems. In addition, the data base contains an initial screening table, computed from the cost data, which provides preliminary estimates of the modification/replacement potential of C-E end items. This screening device may be used both for initial evaluation of end items of interest and as a means of identifying which end items should be studied further.

Once an end item has been selected for study, the cost prediction submodel of COSTCASTER may be used to forecast O&S costs for the item based on the historical costs in the data base. The submodel presents, in both graphical and tabular form, the historical and forecasted O&S costs along with prediction bands for the forecasts. The submodel also produces a table of diagnostics which allows the user to assess the reliability of the forecasts.

These outputs are designed to give the user a sense of the historical costs for the end item, and some idea of the reasonableness of the cost estimates produced by COSTCASTER. The projections from the

model can then be used to identify end items which are good candidates for modification or replacement.

Given the projected O&S costs from the cost-prediction submodel, the trade-off assessment submodel may be used to estimate the economic benefits of a modification or replacement decision. This submodel permits extensive user input in order to refine those estimates. A major output product is a savings contour plot which shows the estimated total savings as a function of (1) the expected reduction in O&S costs for the new or modified end item and (2) the expected economic lifetime of that item. These contours provide instant visibility of how the estimates of savings are affected by changing the basic assumptions. The trade-off assessment submodel also produces a second contour plot which shows the short-term cost avoidance expected to result from a replacement/modification decision.

COSTCASTER provides several additional output products, including estimates of the economic effects of delaying the modification/replacement decision. Base and depot maintenance data are also provided as an aid in identifying subassemblies which account for a disproportional share of an end item's O&S costs. In such cases, modification of the end item might be in order.

Trade-off decisions require consideration of both costs and the operational effectiveness of the end item. COSTCASTER is designed to help the analyst obtain forecasts of future O&S costs and accurate estimates of the savings associated with a potential modification/replacement decision. Thus, while the model does not consider the opera-

tional-effectiveness factors involved in a modification/replacement decision, it can be used as an effective decision tool in the overall trade-off process.

TABLE OF CONTENTS

I. INTRODUCTION

This report describes the methodology underlying COSTCASTER, a cost-prediction and trade-off model being developed by Desmatics, Inc. under Air Force Contract No. F33600-82-C-0466. This model is intended for use as a decision aid in determining whether to modify, replace, or retain Air Force ground communications-electronics (C-E) equipment. Specifically, COSTCASTER is designed to provide the user with forecasts of future O&S costs and accurate estimates of savings associated with potential modification/replacement decisions.

Section II of this report gives an overview of COSTCASTER and describes the various capabilities of the model. The remaining sections are devoted to a more detailed description of COSTCASTER. Section III describes the annual, routine processing which is done to produce the COSTCASTER data base. Section IV describes the details of the statistical framework used in the cost-prediction submodel for forecasting, and discusses the underlying assumptions. In addition, a description is given of several diagnostic measures which may be used to evaluate the reliability of the cost predictions.

Section V provides details of the methods used in the trade-off assessment submodel. The assumptions used in this submodel in the estimation of savings are discussed, along with a means of evaluating the sensitivity of the estimates to those assumptions. Details of the provisions made for user input to COSTCASTER are also included in this section.

COSTCASTER is designed to provide accurate cost information for use in replacement/modification decisions. Section VI provides a summary of the decision-making process and discusses the role of COSTCASTER in that process.

OF COSTCASTER

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aluating modification/replacement
. Toward this end, COSTCASTER is

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fication/replacement

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methodology, discuss underlying
output products.

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D160A:

(1) National Stock Number
(2) Type Model Series (TM
(3) Standard Reporting De
(4) Nomenclature
(5) Estimated ten year O&
(6) Unit price
(7) Average inventory for
and (8) BERP.

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The preprocessor outputs printe
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While the BERP table may b

for selecting end items of interest, the cost-prediction and trade-off submodels of COSTCASTER allow for a more detailed assessment of the replacement/modification potential of a particular end item.

B. COST-PREDICTION SUBMODEL

Historical cost data in the COSTCASTER data base is input to the cost-prediction submodel, which employs statistical regression techniques to forecast O&S costs for future years. As specified by the user, these predictions may be made for:

(1) total O&S costs,

(2) costs for a single D160A O&S cost category (e.g., base maintenance personnel),

and (3) for any group of D160A O&S cost categories of interest to the user (e.g., all personnel costs).

Both graphical and tabular outputs are produced by the cost-prediction submodel. The graphical output, which consists of a plot of the predicted future O&S costs, displays the trend in costs over time. The output also includes a visual presentation of statistical prediction intervals, which indicate how far future costs might reasonably be expected to deviate from the predicted values.

Corresponding tabular output is also produced by the cost-prediction submodel. In addition, this submodel furnishes diagnostic information for evaluating the reliability of the cost predictions, and provides input to the trade-off assessment submodel.

C. TRADE-OFF ASSESSMENT SUBMODEL

Using the estimated future O&S costs, the trade-off assessment submodel estimates the economic benefits of a possible modification/replacement decision. A major output from this submodel is a contour plot which shows expected savings as a function of the percent reduction in O&S costs and the economic life of the replacement end item. The contours not only provide estimates of savings, but also allow for easily examining the sensitivity of those estimates to the assumptions about the reduction in O&S costs and the economic life.

A second contour plot produced by this submodel shows estimated cost avoidance as a function of time and the expected reduction in O&S costs. These contours provide visibility of the short-term benefits expected as a result of replacement or modification. In particular, the break-even ($0) contour line provides an estimate of how long it will take the new or modified end item to "pay for itself" as a function of the reduction in O&S costs.

The trade-off assessment submodel is designed to be interactive and to make use of extensive user input. For example, the user may make several assumptions about both the current end item and a contemplated replacement, and then use the model to evaluate the consequences of those assumptions. The assumptions may then be revised and the process repeated.

III. COSTCASTER DATA BASE DEVELOPMENT

The COSTCASTER preprocessor uses annual Air Force cost and maintenance data to build an historical data base tailored to the requirements of the model. In order to facilitate the initial screening of C-E end items for potential modification/replacement candidates, the preprocessor augments the data base with a BERP table. The following sections describe the input data files and the calculation of the BERP values, along with the assumptions used in those calculations.

A. INPUTS TO THE COSTCASTER PREPROCESSOR

The preprocessor develops the COSTCASTER data base using O&S cost data from the D160A system and maintenance data from the D160A feeder systems D056 and H036B. Figure 1 outlines the preprocessing steps. Examples of the type and general format of cost data in the COSTCASTER data base are given in Tables 1 and 2 for a hypothetical multiplexer set. Table 1 displays total annual O&S costs, as well as price and inventory information. Table 2 gives historical costs for each of the 19 O&S cost categories reported by D160A. The data base will, of course, contain similar information for all C-E end items costed by the D160A system.

It should be noted that the multiplexer data for FY79 through FY83, presented in Tables 1 and 2, is purely illustrative. In fact, because D160A is a relatively new system, cost data is available only for FY81 and succeeding years. For initial applications of COSTCASTER, it is

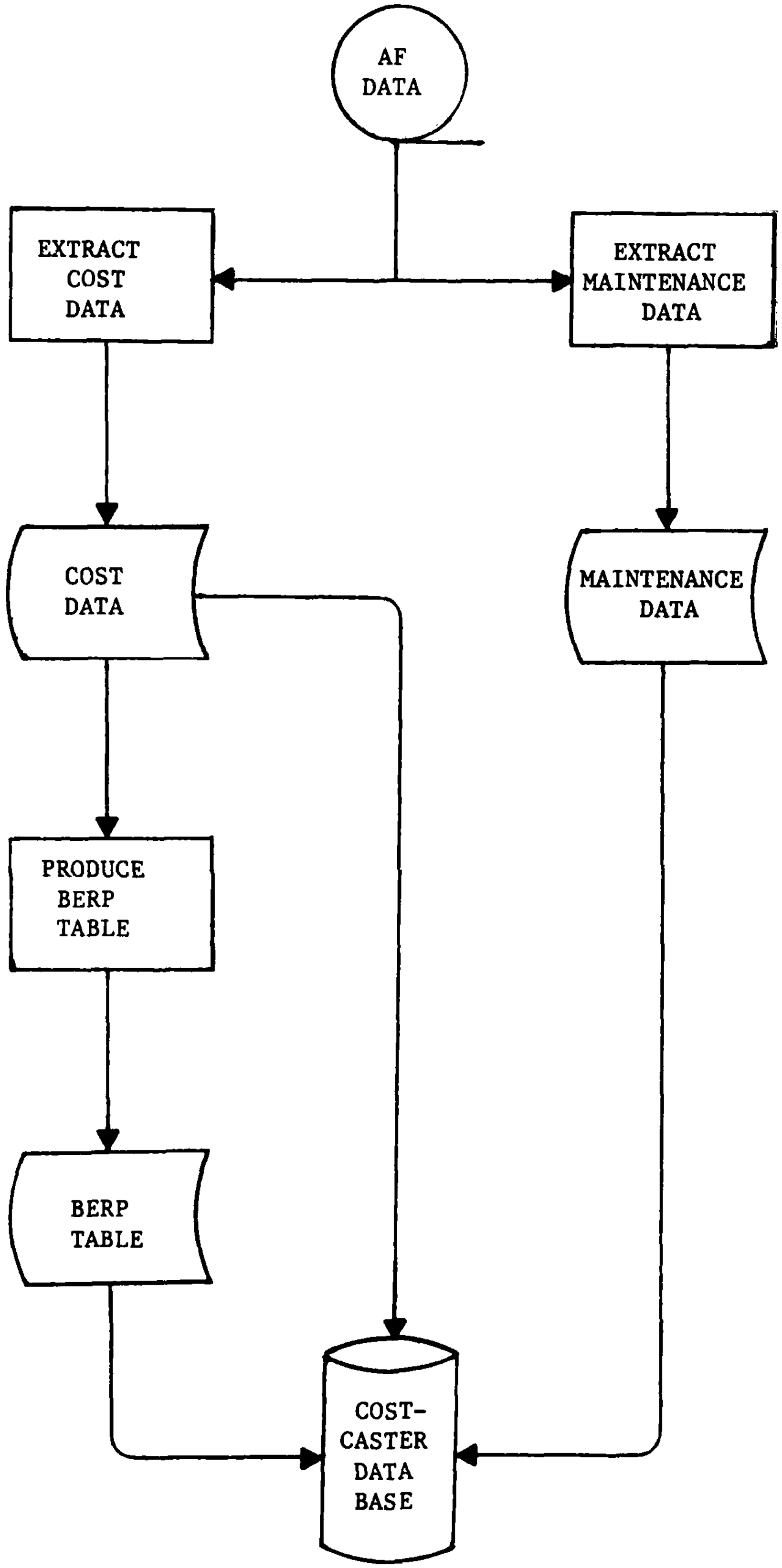


Figure 1: Annual COSTCASTER Data Base Development by the Preprocessor

COSTCASTER DATA INPUT TABLE
(ALL COSTS ARE IN FY84 $)

TMS: AN/FCC-00

NOMENCLATURE: MULTIPLEXER SET

NSN: 9999999999998
9999999999999

SRD: DUM

FY83 AVERAGE INVENTORY: 16.75 FY83 FLEET O&S COST: 622046

NORMALIZED HISTORICAL O&S COSTS ($/UNIT)

FY	NSN	AVG INV	UNIT PRICE	DEFLATION FACTOR	O&S COST
1983	9999999999999	16.75	50000	.950	37137
1982	9999999999999	16.50	50000	.904	35071
1981	9999999999998 9999999999999	1.50 15.00	56000 50000	.828	37986
1980	9999999999998 9999999999999	3.00 13.00	56000 50000	.740	40263
1979	9999999999998 9999999999999	3.00 12.75	56000 50000	.675	42654

NOTE: O&S COST DATA IS FROM D160A, WHICH DOES NOT PROVIDE SEPARATE COST VISIBILITY BY NSN OR SRD.

Table 1: Historical O&S Costs ($/Unit) for a Hypothetical Multiplexer Set

AN/FCC-00 MULTIPLEXER SET DATA INPUT TABLE
DATA LISTED BY COST CATEGORY
(COSTS ARE $/UNIT IN FY84 $)

COST CATEGORY	FY79	% TOT	FY80	% TOT	FY81	% TOT	FY82	% TOT	FY83	% TOT
OPERATIONS PERSONNEL	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
BASE MAINTENANCE PERSONNEL	12237	28.7	12874	32.0	13295	35.0	11072	31.6	13889	37.4
ADMINISTRATIVE PERSONNEL	1706	4.0	1449	3.6	1595	4.2	1353	3.9	1623	4.1
SUPPLY SUPPORT PERSONNEL	555	1.3	413	1.0	456	1.2	534	1.5	668	1.8
FUEL	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
MAINTENANCE MATERIAL	3549	8.3	3141	7.8	2431	6.4	2100	6.0	2265	6.1
UTILITIES	1492	3.5	1289	3.2	1140	3.0	1104	3.1	1077	2.9
DEPOT MAINTENANCE	16720	39.2	16105	40.0	13978	36.8	13493	38.5	13035	35.1
REPLACEMENT INVESTMENT	2602	6.1	1731	4.3	1975	5.2	1780	5.1	1448	3.9
BASE OPERATIONS SUPPORT	852	2.0	564	1.4	684	1.8	783	2.2	557	1.5
REAL PROPERTY MAINTENANCE	511	1.2	604	1.5	494	1.3	498	1.4	483	1.3
COMMUNICATIONS	342	0.8	403	1.0	342	0.9	392	1.1	334	0.9
TEMPORARY DUTY	170	0.4	80	0.2	114	0.3	107	0.3	186	0.5
PERMANENT CHANGE OF STATION	896	2.1	322	0.8	466	1.2	676	1.9	891	2.4
MEDICAL	170	0.4	121	0.3	152	0.4	178	0.5	186	0.5
GENERAL DEPOT SUPPORT	42	0.1	40	0.1	76	0.2	71	0.2	111	0.3
TRANSPORT. AND PACKAGING	810	1.9	1127	2.8	798	2.1	930	2.7	484	1.3
ENGINEERING SUPPORT	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
ADVANCED TRAINING*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
TOTAL O&S	42654	100.0	40263	100.0	37986	100.0	35071	100.0	37137	100.0

*UNAVAILABLE FROM D160A AT THIS TIME

Table 2: Historical O&S Costs ($/Unit) for D160A Cost Categories for a Hypothetical Multiplexer Set

anticipated that the D160A data will be supplemented with FY77-FY80 data from the Logistics Support Cost (LSC) model [5]. LSC data is available for only five cost categories: base maintenance personnel, maintenance materiel, depot maintenance, replacement investment, and transportation/packaging. The D160A system also provides data in these categories (plus 14 more). Thus, the COSTCASTER data base for these five categories can be extended four years by using LSC data.

B. THE BREAK-EVEN REDUCTION POINT

As a first step in identifying those end items which are good candidates for modification or replacement, the COSTCASTER preprocessor calculates the fractional reduction in total O&S cost necessary for the projected cost, over the expected economic lifetime (initially assumed to be ten years), of a new or modified end item to equal the projected cost of the current end item. This fractional reduction (the break-even reduction point or BERP) provides a preliminary estimate of the reduction in O&S costs necessary for a new or modified end item to be economically viable. For example, suppose a multiplexer set currently in use has a BERP of .33. This implies that if the O&S costs for a new or modified multiplexer are at least 33% less than the O&S costs for the current multiplexer, it is cheaper to replace the current multiplexer than to keep it.

The COSTCASTER preprocessor calculates BERP values for all C-E end items costed by D160A, and incorporates them into the data base. In addition, it produces four hard-copy BERP tables. These tables, sorted according to NSN, TMS, SRD, and increasing BERP value, respectively,

provide the user with valuable information. For example, they may be used to quickly locate an end item of interest and to identify those end items which appear to be good candidates for modification or replacement. A sample table, listed alphabetically by TMS, is given in Table 3. It should be noted that for illustrative purposes, a population of only ten TMSs is assumed. The following subsections discuss the calculation of the BERP and the assumptions used in those calculations.

1. Calculating the Break-Even Reduction Point

The break-even reduction point, B, is defined as the ratio of the acquisition cost of a new end item to the present value of the total projected O&S cost of the current end item. This may be expressed symbolically as:

$$B = \frac{A}{\sum_{i=1}^{n} (1+d)^{-i}\hat{C}_i}$$

where A = the acquisition cost of the new or modified end item,

d = the discount rate,

$\hat{C}_i$ = the projected O&S cost for year i for the current end item, using the model described in Section IV,

and n = the remaining economic life (in years) of the current end item.

The value of B is small when the O&S costs of the end item are the major portion of its life cycle costs. In such a case, a new or modified end item with lower O&S costs should be a good investment.

TABLE OF BREAK-EVEN REDUCTION POINTS FOR CE END ITEMS
IN ALPHABETICAL ORDER BY TMS.

TMS	NSN	SRD	NOMENCLATURE	BREAK-EVEN REDUCTION POINT	ESTIMATED TEN YEAR UNIT O&S COST	UNIT PRICE	AVERAGE INVENTORY
AN/FCC-00	9999999999999	DUM	MULTIPLEXER SET	.24	207216	50000	16.75
AN/MRN-99( )	9876543210000	NSA	AIR TRAFFIC CONTROL	.21	423732	87914	8.50
C-7000/G	8765432198765	FBI	TELETYPE CONTROL UNIT	.39	23267	9058	39.25
CEI 999-1	1234567890000	7UP	RADIO RECEIVER	.09	27609	2350	99.00
FE6000A	6666666666666	NBA	FREQUENCY STABILIZER	.46	69064	30856	6.25
GS-00( )	4136071819840	CRX	RECORDER REPRODUCER	.03	78981	2129	123.75
MW-999( )	7417767419760	NFL	UNIVERSAL MWAVE GROUP	.98	30328	29788	5.75
R-9999	8500000000150	Z28	RADIO RECEIVER	.31	11146	3411	68.00
206J1Z	1271941991946	RCA	LINEAR POWER AMP	.57	92610	53000	2.50
45BX00	1029192900000	CIA	MULTIPLEXER	.63	25619	16172	17.00

Table 3: Sample BERP Table

2. Assumptions Made in the Calculation of BERPs

The BERP tables produced by COSTCASTER are intended for use in obtaining rough initial estimates of the replacement/modification potential of C-E end items and as aids in identifying those end items which warrant more detailed investigation. It is necessary to make several assumptions in order to calculate BERPs for all end items costed by the D160A system. (COSTCASTER lists these assumptions prior to displaying the BERP tables.) Once a particular end item has been selected, however, these assumptions may be changed by the user in the trade-off assessment submodel. COSTCASTER makes the following assumptions in calculating BERPs.

1) The economic lifetime of the modified or replacement end item is ten years.

   A ten year economic life for an end item is probably conservative, since many end items actually last 15 or more years.

2) The remaining economic life of the current end item is ten years.

3) The discount rate is 10%.

   This is the discount rate specified by AFR 178-1.

4) The acquisition cost of a modified or replacement end item is the same as the unit price (last-buy price) of the current end item.

   This assumes that R&D costs and most production costs are negligible. For end items which can be bought off-the-shelf, this is probably a reasonable assumption.

If, for an end item, these assumptions are not valid, they will usually lead to an underestimation of the break-even reduction point. The net result of this will be that more end items will appear to be

good candidates for modification than there actually are. This is considered appropriate, since it is better to include for further consideration an end item which is in fact a poor candidate for modification or replacement than it is to exclude an end item which is in fact a good candidate.

As stated above, the BERP value is intended only as an initial estimate of the replacement/modification potential of an end item. More detailed evaluation of a particular end item can be made with the cost-prediction and trade-off submodels which are discussed in the next two sections.

IV. COST-PREDICTION SUBMODEL

A diagrammatic view of COSTCASTER is presented in Figure 2. As can be seen from this figure, the cost data base produced by the preprocessor is input to the cost-prediction submodel which uses the historical cost data to forecast O&S costs for any end item specified by the user. These forecasts are then used as input to the trade-off assessment submodel. This section discusses the statistical model used for forecasting, diagnostic measures which may be used to evaluate the reliability of the forecasts, and the output products from the cost-prediction submodel.

COSTCASTER may be used to forecast either the costs associated with an individual D160A cost category or the combined costs for any set of categories (including the total O&S costs). The forecasts of the combined costs are developed by summing the historical costs over the categories of interest and calculating a single forecast of the total costs for this set of categories.

Figure 3 provides an example of graphical output from the cost-prediction submodel based on the cost data given in Table 2 for the hypothetical multiplexer. The solid line represents the model fitted to the historical cost data points (*'s) and connects the predicted future O&S costs to display the trend in costs over time. The dashed lines provide statistical 95% prediction intervals, which indicate how far future costs might reasonably be expected to deviate from the predicted values. The widths of these bounds are larger for later years since it is more difficult to forecast costs for more distant years. Table 4

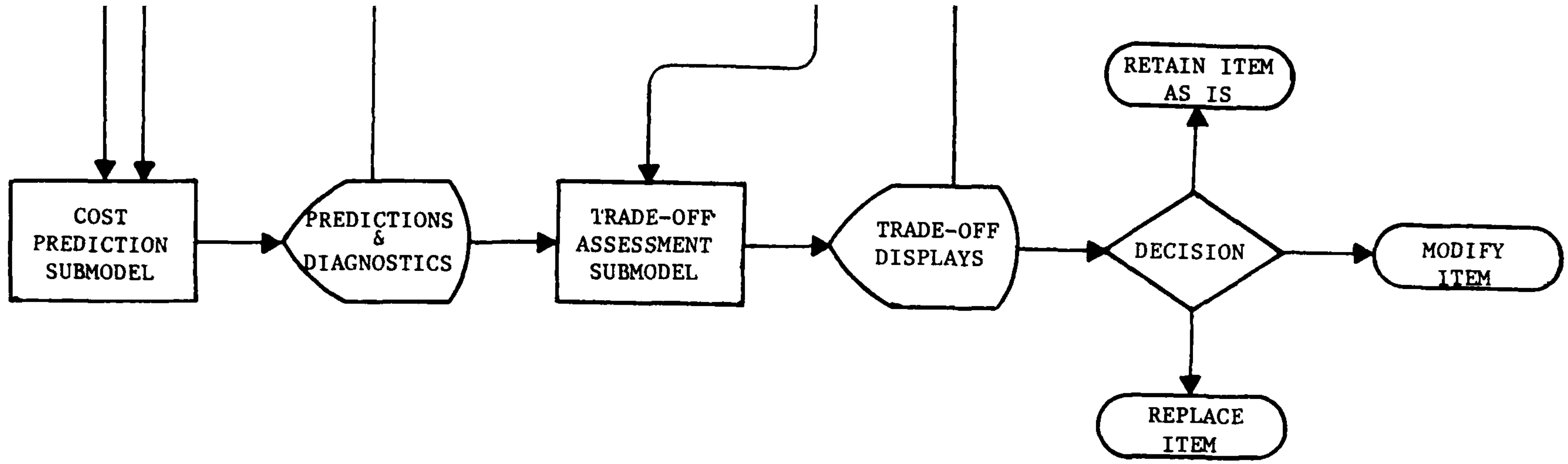
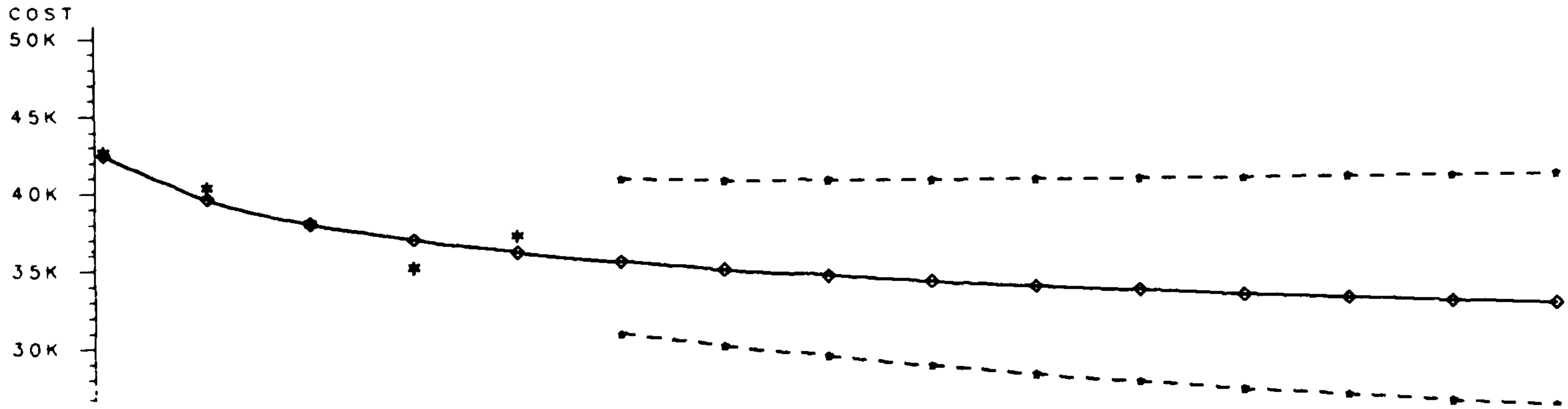


Figure 2: Diagrammatic View of COSTCASTER

AN/FCC-00 MULTIPLEXER SET
Predicted Operating and Support Costs (FY84 Dollars)



PREDICTIONS FOR THE AN/FCC-ØØ MULTIPLEXER SET

PREDICTED COST FOR YEAR T = 42418*T**(-.1Ø15) (FY84 DOLLARS)

FY	T	COST	FORECAST	95% PREDICTION INTERVAL
79	1	42654	.	.
8Ø	2	4Ø263	.	.
81	3	37986	.	.
82	4	35Ø71	.	.
83	5	37137	.	.
84	6	.	35362	(3Ø777, 4Ø631)
85	7	.	34813	(29939, 4Ø481)
86	8	.	34344	(29193, 4Ø4Ø5)
87	9	.	33936	(28527, 4Ø372)
88	1Ø	.	33575	(27929, 4Ø363)
89	11	.	33252	(27388, 4Ø37Ø)
9Ø	12	.	32959	(26898, 4Ø387)
91	13	.	32692	(26449, 4Ø41Ø)
92	14	.	32447	(26Ø36, 4Ø437)
93	15	.	32221	(25655, 4Ø467)

Table 4: Table of Predicted Costs for the Hypothetical Multiplexer

provides an example of the corresponding tabular output produced by the cost-prediction submodel. In addition to the forecasts and prediction limits, the table gives the mathematical function used to obtain the predictions. COSTCASTER also furnishes diagnostic information for evaluating the reliability of the cost predictions. The following sections discuss in detail the relevant aspects of the cost-predication submodel, including the various diagnostic measures.

A. MATHEMATICAL MODEL

The mathematical forecasting model used in COSTCASTER is comprised of two components: (1) a deterministic or nonrandom component and (2) a stochastic or random error component. The following subsections describe these components and discuss other mathematical considerations involved in the cost-prediction submodel.

1. The Deterministic Component

There are several factors which must be considered when selecting a generic model to forecast C-E O&S costs. The model must be flexible enough to describe a wide variety of different situations since the trends in costs can be quite different for different TMSs. However, the model must also be parsimonious if it is to produce reasonable predictions from relatively small data sets. Parsimonious models are

not only more mathematically tractable but also tend to be less strongly influenced by the presence of wild observations (O&S costs for a given TMS in one year which depart markedly from the overall trend for that TMS).

The deterministic structure Desmatics has chosen for modeling C-E O&S costs is:

$$C_t = \alpha t^{\beta}$$

where C_t denotes the cost at time t,

> t denotes time, where t=1 represents the first year in which historical cost data is available. For example, if FY81 is the first year for which cost data is available, then t=1 would correspond to FY81, t=2 would correspond to FY82, etc.

and α and β denote unknown parameters that must be estimated.

This structure provides great flexibility since it allows for both increasing and decreasing cost functions as well as functions with any degree of positive or negative curvature. In addition, Desmatics has found that this model produces reasonable cost predictions when applied to existing historical cost data.

2. The Stochastic Model Component

The deterministic model component specifies the overall trend in costs over time. The stochastic model component models random fluctuations about that trend line, i.e., reflects the inherent variability

in the costs. To incorporate this variability into the model structure, random variables (denoted by ε_t for time t) will be used.

It is assumed that each ε_t has a lognormal distribution, i.e., that the natural logarithm of each ε_t has a normal distribution. Under this assumption, the model structure is multiplicative:

$$C_t = (\alpha t^{\beta})\varepsilon_t$$

The use of a multiplicative model implies that the standard deviation of the cost in a given year is proportional to the level of the trend line in that year. This is not an unreasonable assumption, because as costs increase they tend to have a larger variability associated with them.

3. Variability and Prediction Intervals

The variability in the cost estimate depends upon the variance (σ^2) of the error component. The variance, an unknown quantity which must be estimated, is important because it is used to compute prediction intervals for cost forecasts. The prediction interval describes the inherent variability in the cost estimate. The interval is constructed such that there is a high probability (e.g., 95%) that the true cost is contained in this interval. For example, assume that base maintenance per-

sonnel costs are being estimated for a given TMS for year T+K, given historical data up to year T, and that it is determined that a point estimate of this cost is $40,000, with a 95% prediction interval of ($35,500, $45,000). Then, based on the model assumptions, the probability of the true cost for year T+K being in the above interval would be 95%. Note that the prediction intervals are not symmetric about the point estimate. This is a consequence of the fact that the errors are assumed to be from a lognormal distribution.

The default value for the prediction intervals given by COSTCASTER is 95%. However, in order to provide extra flexibility for the user, other values (80, 90, or 99%) may be specified. The optional value, if any, will also be used in calculating the subsequent diagnostic measures.

4. Fitting the Prediction Models

The prediction models will be fit to the data using least squares regression techniques. The default option in the model is ordinary least squares, which gives each year's cost data equal weight. This is the most reasonable approach if the reliability of the data does not change over time.

COSTCASTER also contains an option whereby the user may choose a weighted least squares regression procedure. Weighted least squares is a method for estimating the parameters and variance component of the model, given that the observed data is weighted as a function of time. The weighting is used to permit recent cost observations to

have more influence than past data. Desmatics feels that weighted least squares may be appropriate in this situation for two reasons. First, D160A is an evolving data system and the quality of the data available from it is improving over time. Second, weighting adds flexibility to the model. It is possible that for some end items the trend in costs over time might be too complex to be well modeled by the prediction model used in COSTCASTER. Weighting allows the model to be influenced primarily by the most recent observations and therefore do a better job of fitting the current trend in costs, even if the entire cost history cannot be fit well.

There is no single weighting scheme which is obviously best for forecasting C-E O&S costs and the particular choice made must be to some extent arbitrary. Desmatics has chosen two optional weighting schemes to be included in COSTCASTER. The first is linear weighting, wherein data from the k^{th} of T years is given a weight of k/T. The second optional weighting scheme is geometric weighting. In this scheme the k^{th} year's data receives a weight of r^{T-k}, where r is a weighting ratio ($0 < r < 1$) which must be specified by the user. Both of these weighting schemes are reasonable and have been found to give sensible results when applied to existing data. It should be noted that linear weighting was used to produce the sample forecasts given in this report.

B. DIAGNOSTIC MEASURES OF PREDICTION RELIABILITY

It is important to assess how well any model forecasts real-world

data in order to be able to judge how much credence to put in its results. Therefore, Desmatics has provided for such assessment as an integral part of its cost-prediction model. The following three sections describe diagnostic measures which can be used to assess how well the model is predicting O&S costs. These diagnostic measures are provided as optional output.

1. Accuracy Indices

The most obvious measures of how well the modeling process forecasts costs are given by the differences between the observed cost at a particular time and those costs predicted by the model in earlier years. As each new data point is obtained, these differences (residuals) are calculated using predictions made in the previous year. The residuals are defined as follows:

$$RES(t+1|t) = COST(t+1) - PRED(t+1|t)$$

where COST(t+1) denotes the observed cost for year t+1,

and PRED(t+1|t) denotes the predicted cost for year t+1 using the estimated model parameters from year t.

If these residuals are small, then the predictions made in earlier years have turned out to be accurate. It therefore seems reasonable to suppose that future predictions will maintain that accuracy.

While the residuals measure the absolute accuracy of the forecasts, they tend to increase as costs increase, reflecting the inherent variability in the costs. A more stable measure of accuracy is given

by the relative size of the residual. Therefore, a relative accuracy index, expressed as a percentage, is also reported. This index is defined as:

$$RAI(t+1|t) = 100 \left[\frac{RES(t+1|t)}{PRED(t+1|t)} \right] \% .$$

Both the residuals and the relative accuracy indices are displayed by COSTCASTER. The smaller in absolute value these measures are, the better the predictions are.

Table 5 displays residuals and relative accuracy indices for the multiplexer example. The user examining this table can see, for example, that predictions for FY82 and FY83 have missed the costs actually observed by -5.1% and 7.7%, respectively.

2. Stability Index

If the cost prediction process is performing well, then the models fit in two consecutive years should be very similar. In particular, forecasts generated in the two years should be very close. On the other hand, if consecutive years give widely different forecasts, there is a good possibility that neither set of forecasts is accurate. In order to measure the stability (and thus the reliability) of forecasts, the following index is used:

$$SI(t+2) = 100 \left[\frac{PRED(t+2|t+1) - PRED(t+2|t)}{PRED(t+2|t)} \right] \%.$$

ACCURACY INDICES

FY	RESIDUAL	RELATIVE ACCURACY
82	-1904	-5.1%
83	2671	7.7%

FY	STABILITY INDEX
83	-4.6%
84	6.4%

FY	PRECISION INDEX
82	20.3%
83	13.1%
84	13.3%

Table 5: Prediction Diagnostics for the Hypothetical AN/FCC-00 Multiplexer Set

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Table 5: Prediction Diagnostics for the Hypothetical AN/FCC-00 Multiplexer Set

This stability index measures the percentage change in predicted cost for year t+2, using predictions made in years t and t+1, respectively. Of course, it is desirable to have stability indices which are small in absolute value.

For the multiplexer example, as shown in Table 5, the stability index for FY83 indicates that the prediction made for FY83 in FY82 was 4.5% less than that made in FY81. The predictions made for FY84 in FY82 and FY83, respectively, differ by 5.4%.

3. Precision Index

As discussed, 95% prediction intervals are constructed around each of the forecasts from the prediction models. These intervals quantify how far a new data point can reasonably be expected to deviate from its predicted value. Therefore, the widths of these intervals give an indication of the precision of the forecasts. As more data points become available, the models should provide more accurate descriptions of cost behavior. This should in turn provide more precise estimates. In order to measure this increase in precision, a precision index is defined as follows:

$$PI(t+1) = 50 \left[\frac{PIW(t+1|t)}{PRED(t+1|t)} \right] \%$$

where $PIW(t+1|t)$ denotes the width of the prediction interval for year t+1 using the model from year t.

This index measures percent deviation from the predicted value. It

gives an upper bound on how far the next year's cost can reasonably be expected to deviate from the one-year forecast. Like the indices previously discussed, the smaller the value of the precision index, the better. From Table 5 it can be seen that the precision index for FY82 was 20.3% and that it dropped to about 13% in succeeding years.

C. OUTPUTS FROM THE COST-PREDICTION SUBMODEL

In summary, the user may obtain two principal outputs from the cost-prediction submodel for any end item of interest. These are:

(1) a graphical display of the historical and projected costs with prediction bands for the forecasts (Figure 3),

and (2) a table displaying the estimated prediction model, historical costs, predictions, and prediction intervals (Table 4).

An additional optional output (Table 5) of diagnostic measures can be used to evaluate the performance of the prediction process.

These outputs are designed to give the user a sense of the historical costs for the end item, and some idea of the reasonableness of the cost estimates produced by COSTCASTER. The projections from the model can then be used to identify end items which are good candidates for modification or replacement. This identification process is discussed in the next section.

:SSMENT SUBMODEL

lel of COSTCASTER uses the output
to produce estimates of the savings
icing an end item. These savings
the estimated reduction in O&S
l or replacement item, may be used in
:-E end items. In order to make these
, the user is able to specify several
ig sections discuss these user inputs
:e the savings in O&S costs.

.ngs associated with a modification/
iary to specify the values of several
ied by COSTCASTER are reasonable,
it the end item of interest. However,
and its mission may be able to
us obtain better estimates of savings.
option of specifying:

f not specified, 10% is used.)

of the modified or replacement
the unit price of the current

etime (in years) of the modified
m, and the expected remaining
ent end item, n. (If not
ten years is used for each.)

-

4) The expected fractional
cost category i for the
(If not specified, an e:

5) The expected O&S costs
its economic life. (If
dictions from COSTCASTE

These input options give the use
analysis any estimates of econom
costs which are felt to be bette
model. Note that a discount rat
Analysis and Program Evaluation
[2]. However, the Economic Ana
say that if the use of a discount
an analysis should be done using

These inputs are used to ca

1) The expected savings as
replacing the current e

2) The expected overall re

and 3) The expected savings as
replacing the current e

How these savings are calculated

B. CALCULATING EXPECTED SAVINGS

COSTCASTER produces two cont
to examine the economic benefits
tion or replacement decision. Th
savings over the remaining econom

takes into account the residual value of the new or modified item. The second plot, on the other hand, estimates short-term cost avoidance which is the reduction in O&S costs minus the acquisition cost of the new or modified item. While the first plot may be used to examine the feasibility of a replacement/modification decision, the second plot provides estimates of the immediate economic benefits to be gained from that decision.

1. Expected Total Savings

The expected total savings that will result from immediately modifying or replacing the current end item is given by:

Savings = the present value of projected O&S cost of the current end item over its remaining economic life of n years

- the acquisition cost of the modified or replacement end item

- the present value of the projected O&S costs for the new item over the next n years

+ the residual value of the new item after n years, based on straight-line depreciation.

(This assumes that the replacement or modified end item will last at least as long as the remaining life of the current item.) This may be represented symbolically as:

$$S = \sum_{i=1}^{n} (1+d)^{-i}\hat{C}_i - A - (1-R) \sum_{i=1}^{n} (1+d)^{-i}\hat{C}_i + (1+d)^{-n}\left(\frac{m-n}{m}\right)A$$

where S = Expected savings,

d = Discount rate,

$\hat{C}_i$ = Projected O&S cost for the current end item for the i^{th} future year,

A = Acquisition cost of the new end item,

R = Expected fractional reduction in O&S costs,

n = Remaining economic life, in years, of the current end item,

and m = Economic life, in years, of the new end item ($m \geq n$).

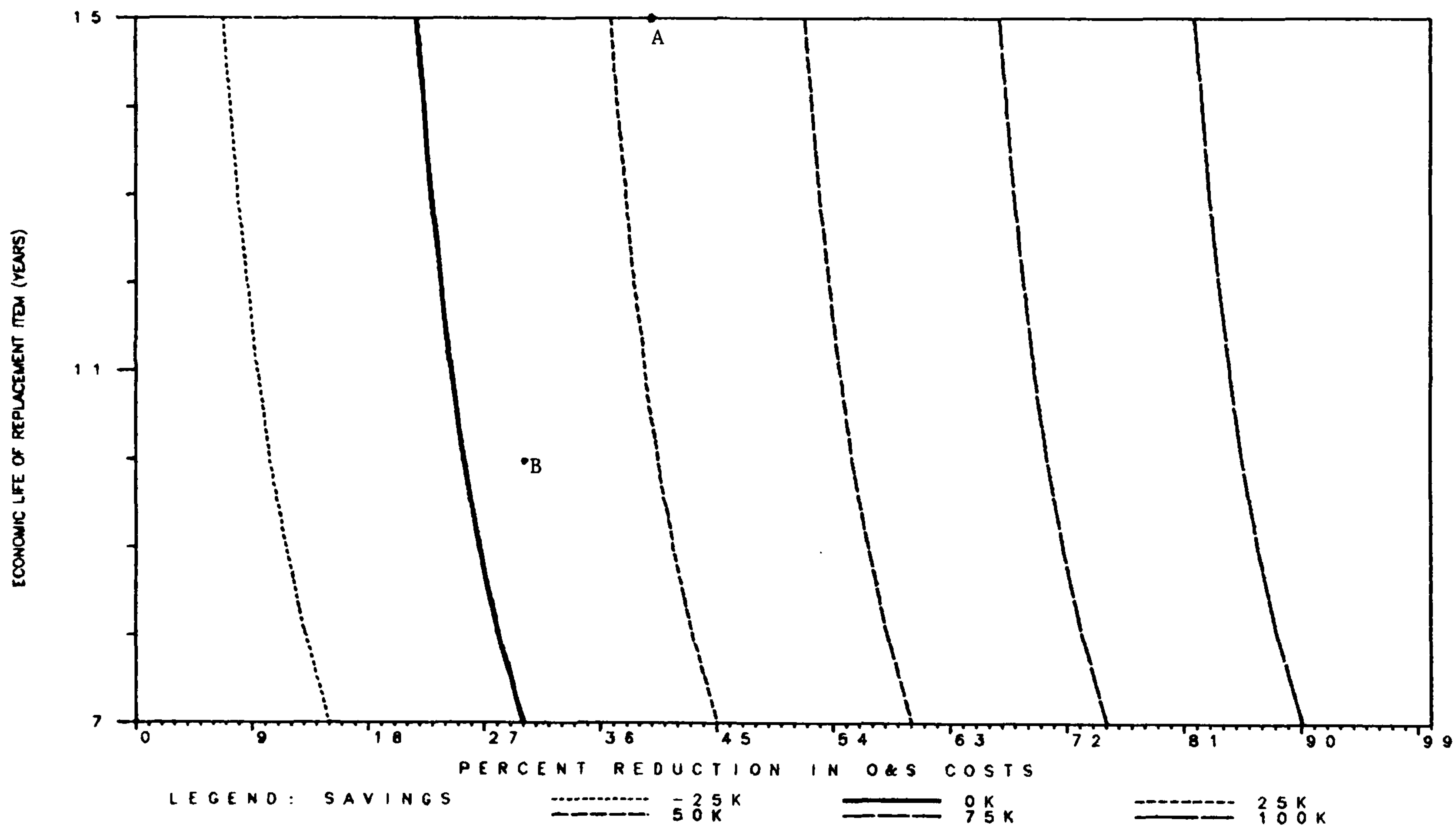
This equation reduces to:

$$S = R \sum_{i=1}^{n} (1+d)^{-i}\hat{C}_i - A[1-(1+d)^{-n}(\frac{m-n}{m})].$$

A major output from the trade-off assessment submodel is a contour plot which shows expected savings as a function of the percent reduction in O&S costs and the economic life of the replacement end item. Figure 4 shows these contours for the hypothetical multiplexer set. The contours not only provide estimates of savings, but also allow for easily examining the sensitivity of those estimates to the assumptions about the reduction in O&S costs and the economic life.

From this figure, it can easily be seen that if the economic life of the replacement end item is 15 years and the reduction in O&S costs is 40%, then the expected savings per unit over the remaining economic life of the current end item (the next 7 years) is about \$30K.

AN/FCC-00 MULTIPLEXER SET
Expected Total Savings ($/Unit) by Replacing TMS (FY84 Dollars)



Remaining Economic Life of Current End Item is 7 Years
Acquisition Cost is $50000 Discount Rate is 10%

Figure 4: Sample Total Savings Contours

(Point A on Figure 4.) How sensitive savings are to these assumptions can be determined by using the contours to answer "what if" questions. For example, if the economic life is only 10 years instead of 15 years and the reduction in O&S costs is only 30%, a replacement decision would still result in savings, but only about $10K. (Point B on Figure 4.) Depending on the shape of the contours, such changed assumptions might result in a loss instead of a savings.

The savings contour lines are nearly vertical for the multiplexer example, indicating that the estimates of savings are relatively insensitive to assumptions about the economic life of the new item. This will be true in general for a current end item with large O&S costs relative to its acquisition cost, especially if the current item is assumed to have a long remaining lifetime. In this case, the residual value of the new item is relatively insignificant compared to the potential savings in O&S costs over the remaining life of the current item.

Thus, the contours provide valuable information for evaluating the consequences of assumptions, since they enable the user to easily see the expected savings (or losses) associated with different reductions in O&S costs and different economic lifetimes. In addition to the graphical contour output, the trade-off assessment submodel permits the user to have printed out the savings associated with any given input value of reduction in O&S costs and of economic life.

2. Short-Term Cost Avoidance

It is assumed that any new or modified end item will have lower O&S costs than the current end item. Positive cost avoidance results when this reduction is substantial enough to offset the acquisition cost of the new or modified item. This, of course, depends on the time frame considered and the assumed fractional reduction in O&S costs. For an immediate modification/replacement decision, the cost avoidance (CA) over the next y years is:

CA = the present value of the projected O&S costs of the current end item over the next y years

- the acquisition cost of the modified or replacement end item

- the present value of the projected O&S costs for the new item over the next y years,

where y cannot exceed the remaining economic life of the current end item. This may be represented symbolically as:

$$CA = \sum_{i=1}^{y} (1+d)^{-i}\hat{C}_i - A - (1-R) \sum_{i=1}^{y} (1+d)^{-i}\hat{C}_i$$

where y = The time frame of interest (in years),

d = Discount rate,

$\hat{C}_i$ = Projected O&S cost for the current end item for the ith future year,

A = Acquisition cost of the new item,

and R = Expected fractional reduction in O&S costs.

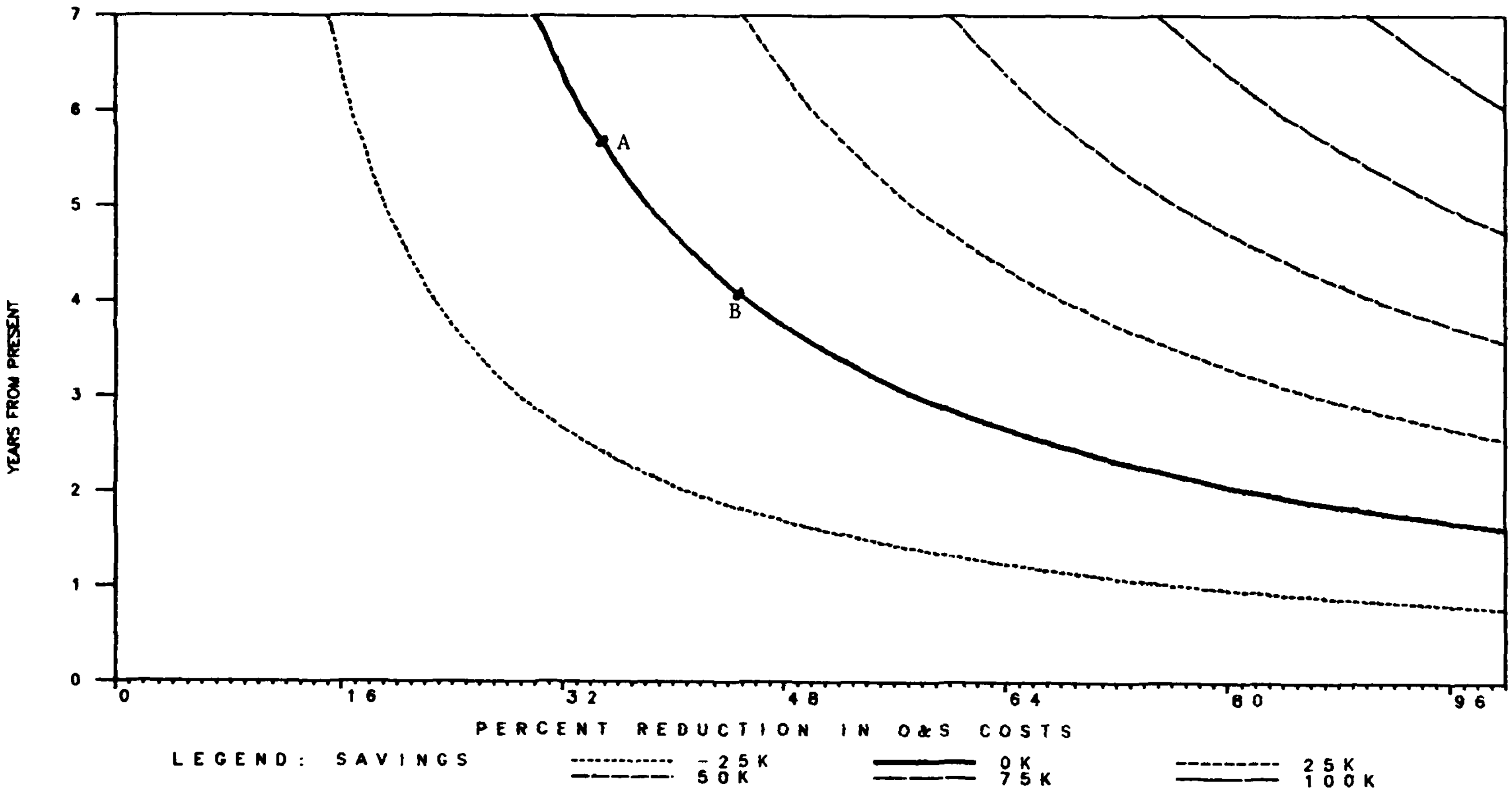
This reduces to:

$$CA = R \sum_{i=1}^{y} (1+d)^{-i} \hat{C}_i - A.$$

The trade-off assessment submodel outputs a second contour plot which shows cost avoidance as a function of the time frame and the expected reduction in O&S costs. Figure 5 shows these contours for the hypothetical multiplexer set.

Of particular interest in this contour plot is the "payback" line, or zero cost avoidance contour. The payback line shows the analyst how long it will take to amortize the investment for the new or modified item as a function of the expected fractional reduction in O&S costs. For the hypothetical multiplexer set, for example, a 35% reduction in O&S costs implies that the acquisition cost will be offset in about 6 years. (Point A on Figure 5) With a 45% reduction, on the other hand, only about 4 years would be required. (Point B on Figure 5) If the percent reduction were less than about 30%, the acquisition cost could not be offset over the remaining economic life of the current item. However, even in that case replacement or modification might be warranted if the new item had a long economic lifetime (and thus high residual value). From Figure 4 it can be seen that even if there were only a 25% reduction in O&S costs for the multiplexer, there would still be some savings if the economic life of the new item were 11 years or more.

AN/FCC-00 MULTIPLEXER SET
Cost Avoidance ($/Unit) by Replacing TMS (FY84 Dollars)



Remaining Economic Life of Current End Item is 7 Years
Acquisition Cost is $50000 Discount Rate is 10%

Figure 5: Sample Cost Avoidance Contours

C. CALCULATING THE EXPECTED REDUCTION IN O&S COSTS

When the user desires to estimate the total savings for a set of C-E cost categories, it is necessary to specify an overall expected reduction in O&S cost for the combined categories. Since it is easier to estimate the reduction for single categories, COSTCASTER has been designed to combine those individual estimates into a total estimate of the combined reduction. This is done by first determining what fraction of the total O&S costs is due to each category. This fraction is calculated by taking a weighted average of the historic cost for the cost category being considered, and dividing this average by a weighted sum of the total O&S costs. The average is taken over both the set of categories of interest and all years for which historical cost data is available. The weights used for the historical costs (equal, linear, or geometric) are the same as those specified by the user in the cost-prediction submodel.

The fraction (F_i) of the combined O&S costs due to a single category i can be expressed by the following equation:

$$F_i = \frac{\sum_{j=1}^{k} w_j C_{ij}}{\sum_{\omega} \sum_{j=1}^{k} w_j C_{ij}}$$

where k = Number of years for which historical costs are available,

w_j = Weight (equal, linear, or geometric) for year j,

C_{ij} = Cost for category i in year j,

and ω = Set of cost categories of interest.

The total predicted fractional reduction in O&S costs is then:

$$\sum_{\omega} F_i R_i$$

where F_i = Fraction of total cost associated with category i,

R_i = Expected reduction in O&S costs for category i,

and ω = Set of cost categories of interest.

D. DETERMINING WHEN TO MODIFY OR REPLACE THE END ITEM

The expected savings calculated in the previous sections are those that would result from an immediate modification/replacement decision. This section shows how to calculate the expected savings that would result if the replacement/modification were made in some future year. The expected savings that would result from modifying or replacing the current end item N years in the future is the projected O&S cost avoidance associated with the new item from the time it is purchased to the end of the current item's economic life minus the acquisition cost of the new item plus the residual value of the new item after the n^{th} year (the remaining economic life of the current item). Of course, the present value of all costs must be used. The expected savings may be expressed as:

$$S = R \sum_{i=N+1}^{n} (1+d)^{-i}\hat{C}_i - (1+d)^{-N}A + (1+d)^{-n}\left(\frac{m-n+N}{m}\right)A.$$

where S = Expected savings,

d = Discount rate,

n = Remaining economic life of the current end item (in years),

m = Economic lifetime of the new end item (in years),

$\hat{C}_i$ = Projected O&S cost for the current item for the i^{th} future year,

R = The expected fractional reduction in O&S costs,

A = Acquisition cost of the new item,

and N = Number of years delay before modification or replacement ($N \leq n$).

Table 6 illustrates these calculations for the multiplexer example. Using the input values listed below the table, if the AN/FCC-00 multiplexer is replaced immediately, the expected savings over the next 7 years are $13,613 per unit. However, if it is replaced three years from now, the expected savings are $5162 per unit.

E. IDENTIFYING SUBASSEMBLIES WITH LARGE O&S COSTS

If a large proportion of the O&S costs of an end item is associated with a particular subassembly of the item, it may be better to modify the item than to replace it. As an aid in determining which subassemblies of an end item may have large O&S costs, COSTCASTER provides a table of the number of maintenance actions and maintenance manhours identified by work unit code (WUC). COSTCASTER also produces a table of recoverable components, identified by NSN. Tables 7 and 8 are examples of this COSTCASTER output for the hypothetical multiplexer.

EXPECTED SAVINGS IF REPLACEMENT IS ACCOMPLISHED N YEARS FROM PRESENT

AN/FCC-ØØ MULTIPLEXER SET

NUMBER OF YEARS (N) TO REPLACEMENT	SAVINGS
Ø	13613
1	1Ø225
2	7436
3	5162
4	3334
5	1895
6	797

NOTE: SAVINGS ARE PER UNIT OVER REMAINING ECONOMIC LIFE OF CURRENT TMS (7 YEARS).

ECONOMIC LIFE OF REPLACEMENT TMS = 15 YEARS

PERCENTAGE REDUCTION IN O&S COSTS = 3Ø

DISCOUNT RATE = .1Ø

ACQUISITION COST= 5ØØØØ

Table 6: Results of Delaying Decision to Modify or Replace End Item

NUMBER OF MAINTENANCE ACTIONS FOR AN/FCC-ØØ MULTIPLEXER SET
TOP 2Ø WUCS RANKED BY NUMBER OF MAINTENANCE ACTIONS

WORK UNIT CODE	NUMBER OF MAINT. ACT. FY83	PERCENTAGE OF MAINT. ACT. FY83	MAINTENANCE MANHOURS FY83	WORK UNIT CODE	NUMBER OF MAINT. ACT. FY82	PERCENTAGE OF MAINT. ACT. FY82	MAINTENANCE MANHOURS FY82
AAØØØ *	6	15.ØØ	24.2	AAAØØ *	4	11.43	12.3
AAANØ *	6	15.ØØ	57.5	AABGA *	4	11.43	4.5
AAAEØ	3	7.5Ø	3.2	AAANØ *	3	8.57	4.Ø
AAANB	3	7.5Ø	7.7	AABGØ *	3	8.57	3.5
AAAØØ *	2	5.ØØ	2.5	AAEAØ	3	8.57	3.Ø
AAAMØ	2	5.ØØ	3.7	AAANA	2	5.71	2.5
AAANJ *	2	5.ØØ	11.Ø	AAANJ *	2	5.71	3.3
AAAAØ	1	2.5Ø	4.3	AABVØ	2	5.71	6.Ø
AAABØ *	1	2.5Ø	Ø.3	AACEH	2	5.71	1.3
AAADV	1	2.5Ø	Ø.2	AAØØØ *	1	2.86	2.5
AAAEJ	1	2.5Ø	2.Ø	AAABØ *	1	2.86	3.3
AAAFØ	1	2.5Ø	12.Ø	AAANH	1	2.86	2.3
AAAFG	1	2.5Ø	3.5	AAAPØ *	1	2.86	5.Ø
AAAGØ	1	2.5Ø	1.5	AABØØ	1	2.86	1.Ø
AAAGF	1	2.5Ø	2.5	AABBØ	1	2.86	4.Ø
AAAKØ	1	2.5Ø	7.3	AABED	1	2.86	1.3
AAANE	1	2.5Ø	3.Ø	AABGF	1	2.86	Ø.7
AAAPØ *	1	2.5Ø	1.5	AABKA	1	2.86	1.Ø
AABGØ *	1	2.5Ø	1.Ø	AABKB	1	2.86	1.Ø
AABGA *	1	2.5Ø	Ø.5	AAAHØ	Ø	Ø.ØØ	Ø.Ø

MANHOURS DO NOT INCLUDE PREVENTATIVE MAINTENANCE INSPECTION (SUPPORT GENERAL) MANHOURS.
THE PMI STANDARD MANHOUR FIGURE FOR THIS ITEM IS: 25 HR/TMS/YR.

* DENOTES COMMONALITY BETWEEN FISCAL YEARS

Table 7: Sample Work Unit Code Table

Table 7 is ranked according to frequency of maintenance actions within each fiscal year. Only the top 20 WUCs are listed, but the user may request a more extensive listing if desired. The user also has the option of requesting a table ranked by maintenance manhours within fiscal year.

The WUC tables allow the analyst to identify which maintenance actions occur most frequently, and how many maintenance manhours are associated with each WUC. It can be seen from Table 7 that the most frequent causes of maintenance for the hypothetical multiplexer in FY83 had WUCs of AA000 and AAAN0; in FY82 the most frequent causes had WUCs of AAA00 and AABGA. The user can then determine if it is reasonable to experience this many maintenance actions, and if these actions should take this long to complete. If the number of maintenance actions or maintenance manhours associated with a subassembly seems excessive, modifications of the subassembly should be considered.

The table of O&S costs for each recoverable component allows the user to determine what proportion of the total depot support costs for each end item is associated with each subassembly. If the depot support costs for a particular subassembly seem excessive, replacement of the subassembly should be considered.

VI. TRADE-OFF ANALYSIS

For every C-E end item currently in use, the Air Force has three options. One option is to replace the current end item with a new end item. A second option is to modify the current item. A third option is to keep the current end item unchanged. The goal of the Desmatics trade-off assessment submodel is to determine systematically which of these three options is best. Two criteria which can be used for deciding which otpion is best are life cycle cost (LCC) and operational effectiveness. The role of COSTCASTER is as a decision aid in answering questions concerning life cycle costs.

A. LIFE CYCLE COSTS

The life cycle cost of an end item is the total dollar value of the resources that will be used by the end item during its economic life. It is comprised of four parts: 1) research and development costs (R&D), 2) production costs, 3) operating and support costs (O&S), and 4) disposal costs.

Research and development costs are the costs of researching, developing, testing and evaluating the system hardware and software associated with an end item. Production costs are the costs associated with introducing an end item into the field. O&S costs are the costs, both direct and indirect, of operating, maintaining, and supporting an end item.

In COSTCASTER, it is assumed that disposal costs are offset by

the salvage value of the end item. Therefore the life cycle cost for an end item can be calculated using the following formula:

$$LCC = D + P + \sum_{i=1}^{m} (1+d)^{-i} C_i$$

where LCC = Life cycle cost

D = Research and development costs, assumed incurred at time of purchase,

P = Production costs, also assumed incurred at time of purchase,

d = Discount rate,

C_i = O&S costs for the i^{th} year,

and m = Economic life (in years).

B. OPERATIONAL EFFECTIVENESS

Operational effectiveness is defined as "how well the system performs its intended mission in its intended environment." [1] For example, suppose two radios are identical in every respect except that radio A is harder to jam than radio B. Radio A would be said to have greater operational effectiveness since it is able to perform its mission (transmitting and receiving while exposed to jamming signals) better than radio B.

A complete discussion of operational effectiveness is beyond the scope of this report, but it is nevertheless often an important factor in choosing between two items. Although the COSTCASTER model does not address operational effectiveness, it does provide forecasts of future

O&S costs and estimates of the savings associated with a potential modification/replacement decision. Thus, COSTCASTER can be used as an effective decision tool in the overall trade-off assessment process.

VII. REFERENCES

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